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Investigation of visual fatigue under LED lighting based on reading task

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ABSTRACT

The light emitting diode (LED) has wide applications recently. However, there are few literatures on the investigation for the influences of LED lighting on visual fatigue or its comparison with the fluorescent lighting. The aim of this study is to analyze the influences of different LED lighting conditions on visual fatigue, especially to discuss the impacts by the lighting condition factors of lighting type (LED or fluorescent lamp), illumination level, correlated color temperature (CCT). In this study, the subjective responses of visual fatigue and task performance were evaluated via a numerical verification experiment under LED and fluorescent lighting conditions, respectively. The experimental results indicate that illuminance, CCT and the type of light source indeed have effects on some symptoms of visual fatigue. Particularly, LED lighting can suppress visual fatigue more effectively than fluorescent one. Moreover, the task performance is not influenced by lighting conditions in these experimental setups.

1. Introduction

Visual fatigue refers to a decrease in performance of the human vision system, which can be induced by long time visual task, repetitive striped patterns or discomfortable lighting condition [1,2]. It can be denoted by visual discomfort, eyestrain, visual stress, asthenopia, and so on, as mentioned in many literatures [1,3,4], and they have no substantial differences and always can be substituted for each other [2].

Generally, visual fatigue can be measured by objective or subjective method. Objective indices of visual fatigue include accommodation, eye movement effects [5] and spatial frequency adaptation [6], whereas subjective methods of visual fatigue take the form of self-report complaints of symptoms such as sore, burning eyes, headaches, double vision and so on [7].

In recent years, with the wide applications of light emitting diode (LED) lamps, there have been several literatures that concentrate on the preference of LED lighting and visual fatigue caused by different LED lighting conditions, including correlated color temperature (CCT) and illuminance. Stefani et al. [8] investigated how the dynamic lighting affected the feeling of well-being and subjective tiredness, which revealed that the tiredness under the dynamic lighting after one working day was significantly lower than that of the static lighting. Lou et al. [2] investigated visual fatigue under six different lighting conditions, which is combined with two levels of illumination (500 lx, 1000 lx) and three levels of CCT (2,700 K, 6,500 K, 10,000 K). Their results indicated that the two lighting conditions (6500 K, 1000 lx) and (2700 K, 500 lx) brought about lowest visual fatigue, but no significant difference existed among their tested six lighting conditions by the analysis of variance (ANOVA). One probable explanation was that a 40-min reading task was too short to induce distinct visual fatigue even if the subjects were exposed in obviously different conditions of illuminance and CCT. The other reason was that visual fatigue was a very comprehensive effect consisted of many symptoms, such as sore, gritty, photophobia, and etc. [3,7,9]. Sheedy and Hayes [10] performed a factor analysis on nine symptoms of visual fatigue at eight visual stressful conditions and found two factors, one was named the internal symptom factor and the other the external symptom factor. In addition, Conlon et al. [11] and Borsting et al. [12] implemented a Rasch analysis on visual fatigue and concluded that the visual discomfort could be expressed by a one-dimensional variable. However, the Rasch analysis could describe only about two-thirds of the overall variation of visual fatigue.

Meanwhile, the spectral power distribution (SPD) of the blue chip based white LED has a peak wavelength at about 450 nm, which is completely different from the SPD of fluorescent lamp. However, the blue light has significant influence on the human circadian system, which may adjust the endocrine system to inhibit

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more melatonin secretion and to promote more cortisol secretion, and can increase the level of arousal, including reduced subjective somnolence and increased heart rate [13–20]. Therefore, LED lamps are expected to have obviously different effects on the visual fatigue and task performance because of their special SPD. Yet, only a few studies investigated whether LED lamps could improve task performance and inhibit visual fatigue. Referring to the relevant results, the aim of this study is to analyze the influences of different lighting condition factors of lighting type (LED or fluorescent lamp), illumination level, and CCT on visual fatigue, especially to discuss their impacts on individual symptoms by circadian stimulus.

2. Methods

2.1. Equipments

In this study, two kinds of LED lighting tubes with different CCTs (3000 K and 6000 K) were employed, which were both constituted of 76 LED chips and with the same power of 8 w. The fluorescent tubes were regarded as a control group to be compared with the two kinds of LED tubes. These three kinds of lighting tubes with the same size (2.5 cm diameter and 59 cm length) were all evaluated in this study, of which the SPDs are shown in Fig. 1. The experimental lighting conditions include not only the three kinds of lighting tubes with the same illuminance of 500 lx, but also the 6000 K LED tubes under three different illumination levels of 350, 500 and 1000 lx, respectively. In addition, in order to control the factor of the light distribution of LED and fluorescent tubes, a light booth capable of being equipped with either of the three kinds of lighting tubes was developed to ensure the uniformity of illumination, expressed by the ratio of the mean to minimum horizontal illuminance of five positions, which was no less than 80% for the whole experiment. The horizontal illuminace of the five positions (four corners and center) on the bottom surface of lighting booth was measured by lux meter. The color of the inner wall in the booth was painted as near as possible to that of N5 in Munsell color order system, which resulted in rather consistent spectral reflectance in visible region. Table 1 summarizes the detailed parameters of all the five

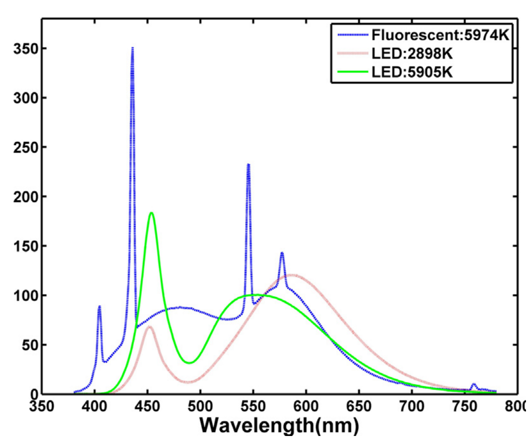

Fig. 1. Relative spectral power distributions of the three kinds of lighting tubes.

Table 1
Summary of parameters for the five lighting conditions in the experiments.

Session	Type	CCT (K)	Mean illuminance (lx)	Uniformity (%)
F6K50	Fluorescent	5974	496	84.2
L3K50	LED	2898	503	85.8
L6K35	LED	5905	352	85.5
L6K50	LED	5905	510	85.4
L6K1K	LED	5905	1011	84.0

Fig. 2. A diagram of the test booth and observer location.

lighting conditions, which are denoted by the session symbols in later discussions.

2.2. Psychophysical procedure

A questionnaire was designed to estimate the influences of different lighting conditions on human perception, which was for measuring visual fatigue, consisted of its 7 items, i.e. sore, heavy, dryness, watery, blurring, double image, and dizziness [7,9]. All the 7 items were graded with a 7-point scale to describe the symptoms of visual fatigue: 1 = Imperceptive, 2 = Just Perceptible, 3 = Perceptible but not Unacceptable, 4 = Just Unacceptable, 5 = Unacceptable but not Intolerable, 6 = Just Intolerable, 7 = Intolerable. In addition, the 2-h numerical verification task was implemented in all sessions [21]. The work performance for these tasks was represented by 3 indices of the reading accuracy, reading rate, and reading efficiency that was defined as a product of reading accuracy and reading rate [22,23]. A ratio of the number of actually verified digits to total number of digits to be verified is defined as the reading accuracy and the number of verified digits per minute by the subjects is defined as reading rate. Hereby, two groups of experimental data were gathered, one was the scores of subjects' evaluation for visual fatigue under different lighting conditions and another was the 3 indices of task performance about reading ability, which could be affected by visual fatigue.

Twelve subjects (six male, six female) participated in the visual experiments, who were all graduate students recruited from Zhejiang University. They all had normal or corrected-to-normal vision, and their ages were in a narrow range from 23 to 34 years old in order to avoid the influences of age-related effects in vision.

The experiments were carried out in a laboratory with dark, the room temperature and the relative humidity of 35–50%. All the experimental sessions were conducted from 9:00 a.m. to 11:00 a.m. or from 2:00 p.m. to 4:00 p.m. so as to simulate the environment of normal office routine. In each session, the subjects were asked to answer the questionnaire after a 5-min dark adaptation and a 2-min light adaptation, and then they conducted a 2-h numerical verification task as rapidly as possible, during which there was no break. At last, the questionnaire would be performed once again after the 2-h visual task to assess the visual fatigue. The five sessions were carried out in a random order. The test numbers were printed by black ink at A4 pages with the 12-point Times New Roman font. The luminance contrast between the black-printed characters and white blank paper was about 15:1 for all sessions, and the view angles for each character and the whole page were about 0.69° and 45.98° respectively with the viewing distance of 35 cm between the eyes of the subjects and the center of the paper, as demonstrated in Fig. 2.